Cost Scaling for Moderate Field Magnets

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Design Options: Low, Intermediate and High Field Magnets

RHIC Dipole: Example of Intermediate Field Magnet

Cost of Magnets

Design Options for Superconducting Dipole Magnets

Low Field (<3T)

NbTi superconductor

Examples: TAC design for SSC

Pipetron

Intermediate Field (3 - 10 T)

NbTi superconductor

Examples: Tevatron, CBA, HERA, UNK, SSC, RHIC, LHC

Designs and costs are understood

High Field (>10T)

No examples---beyond the range of NbTi superconductor

Costs expected to be high $\Rightarrow$ specialized uses

Large forces, expensive superconductor (Nb_3Sn, HTS)

Upgrades to existing machines

IR region magnets

Muon Collider: luminosity proportional to field level

RHIC Dipole

Recent completion of industrial production of 373 dipoles gives solid performance and cost data

Dipole parameters: 10 m long
80 mm coil aperture
3.45 T operating field
144 arc dipoles per ring

Industrial production

- Build-to-print design
- Industry built its own tooling, purchased most parts, built and delivered completed magnets ready for tunnel installation
- BNL provided superconductor, Kapton, beam tubes and quench diodes
- Production rate: one per day

Performance: excellent (to date)

- No rejects or failures
- All magnets suitable for machine use

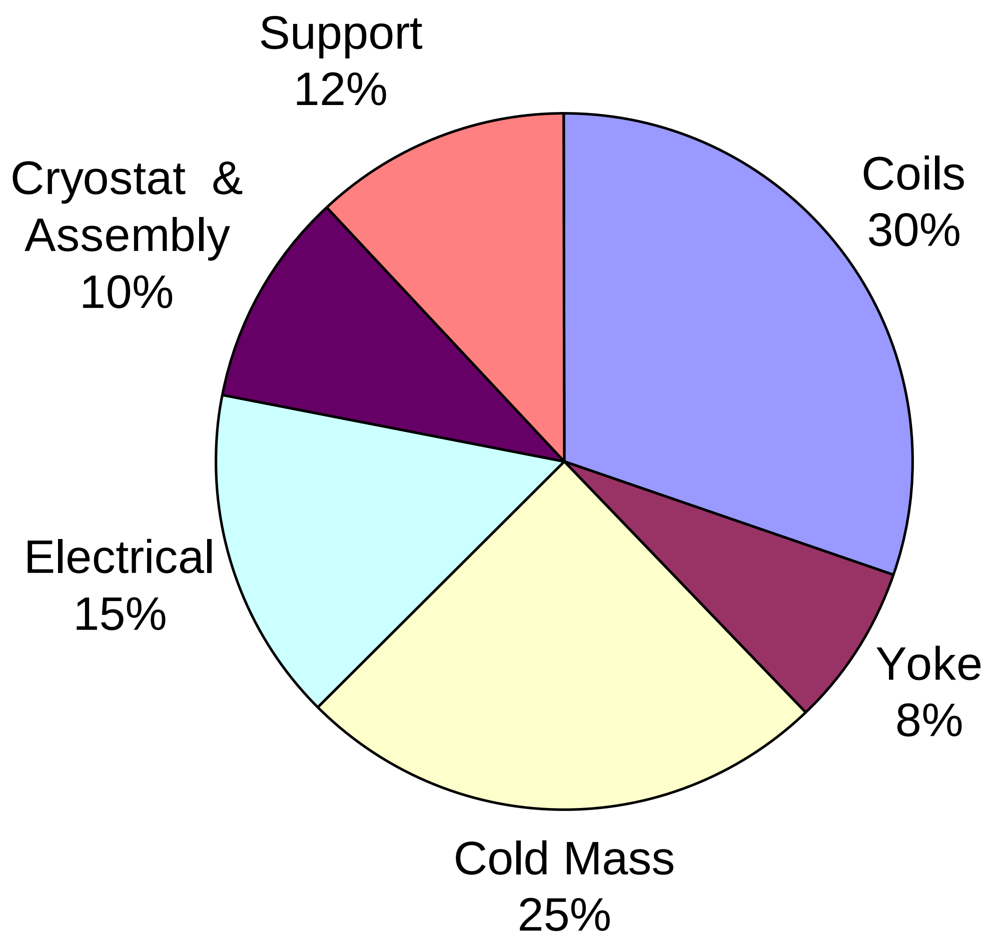
Cost of Magnets

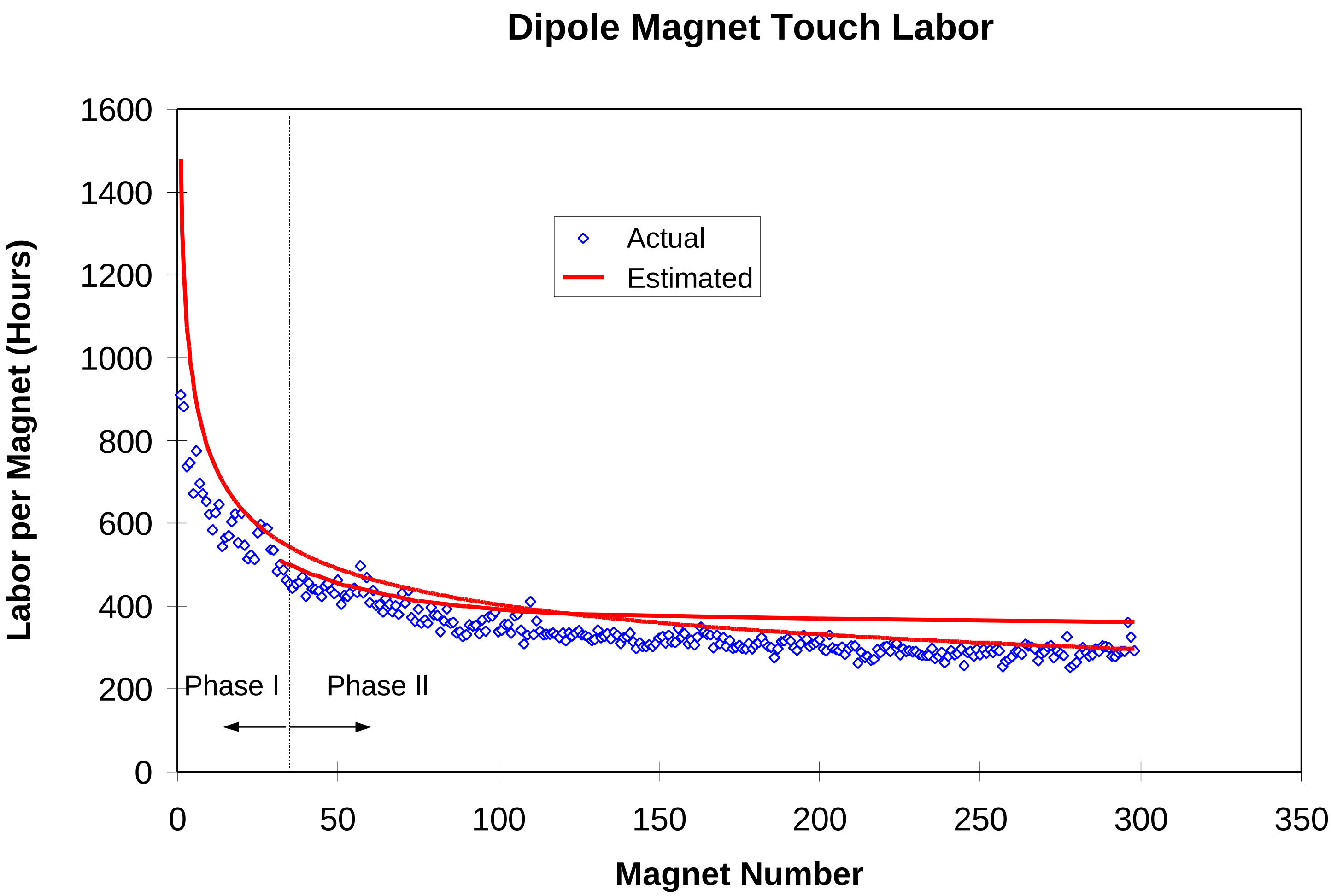
RHIC dipole magnets were bought at a favorable price

- Low cost design of the magnet
- Competitive bidding
- Structure of contract:
  - Build-to-print---no design risk to company
  - Phase I: cost-plus, to cover cost of tooling and 30 magnets training and production debugging
  - Phase II: firm-fixed-price, for high rate production
  - Phase III: firm-fixed-price, for special lengths
- Favorable impact from SSC project: cost of superconductor, steel
- Low point of economic cycle (1991)
- Efficient tooling (guidance from Brookhaven)
- Experienced production team at Grumman

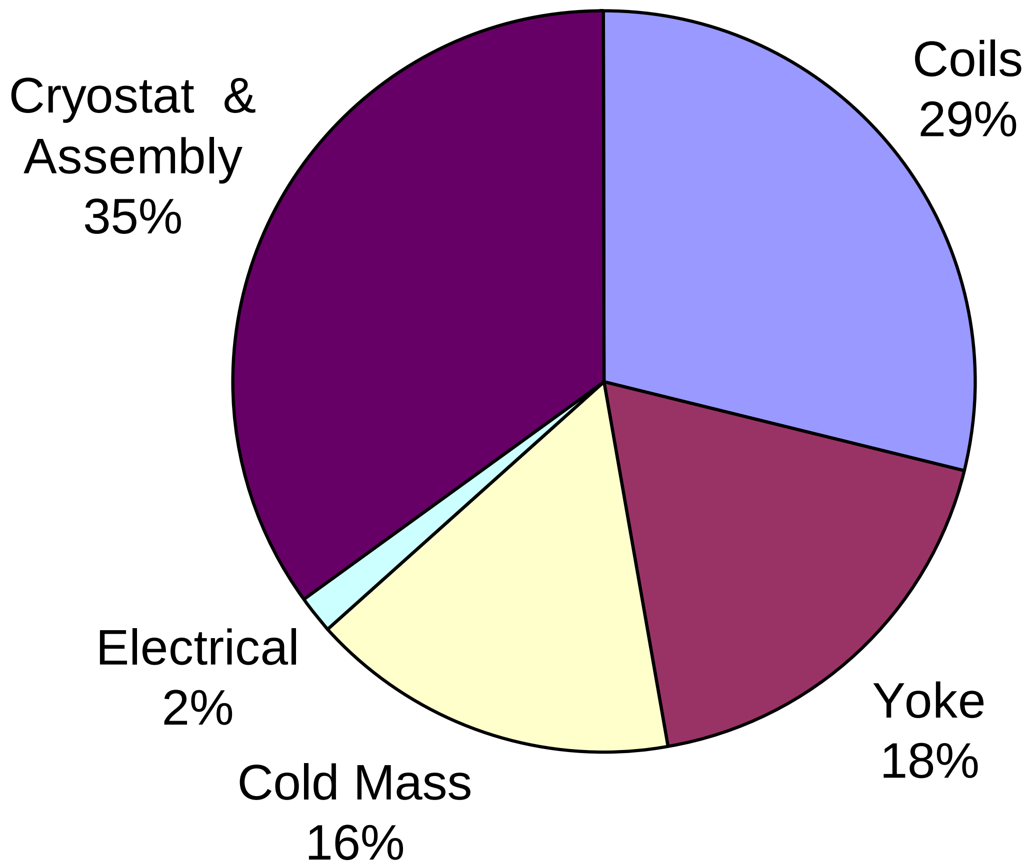
It is unlikely that the cost per magnet of intermediate field, cos θ magnets can be lowered very much

NGC Dipole Magnet Touch Labor Distribution

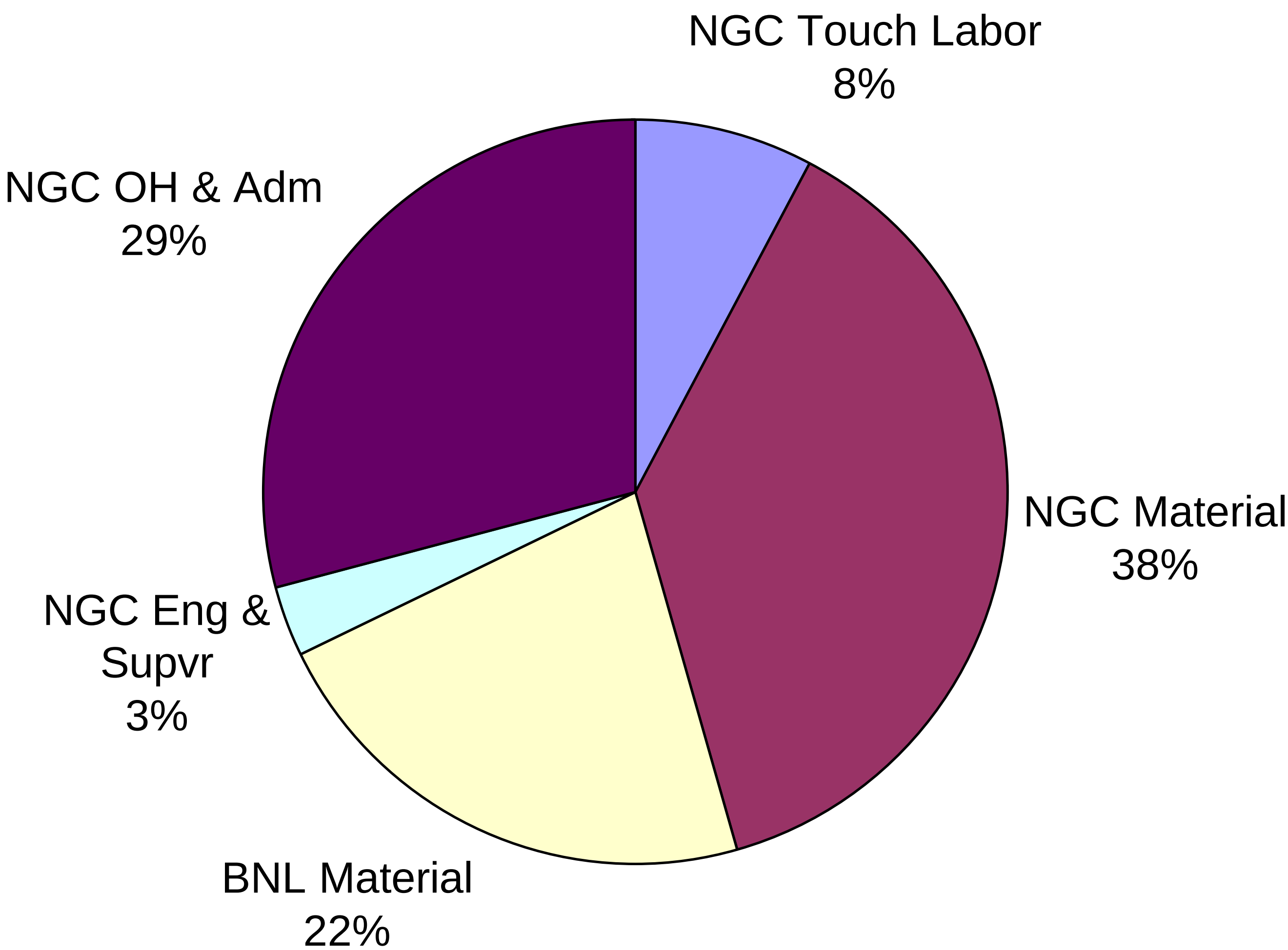



Dipole Magnet Touch Labor
Labor per Magnet (Hours)
Magnet Number
Actual
Estimated
Phase I
Phase II
0
200
400
600
800
1000
1200
1400
1600
0
50
100
150
200
250
300
350

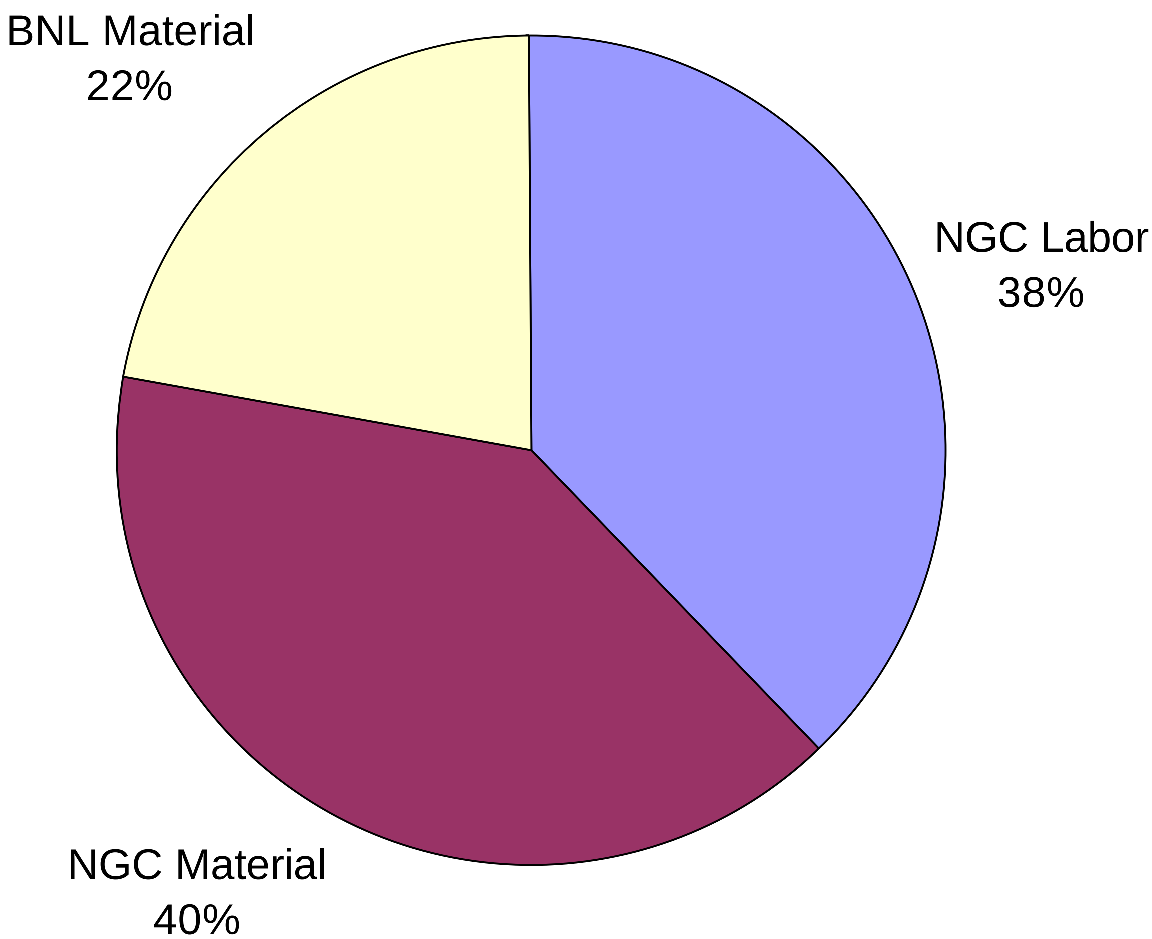
NGC Dipole Magnet Material Cost Distribution



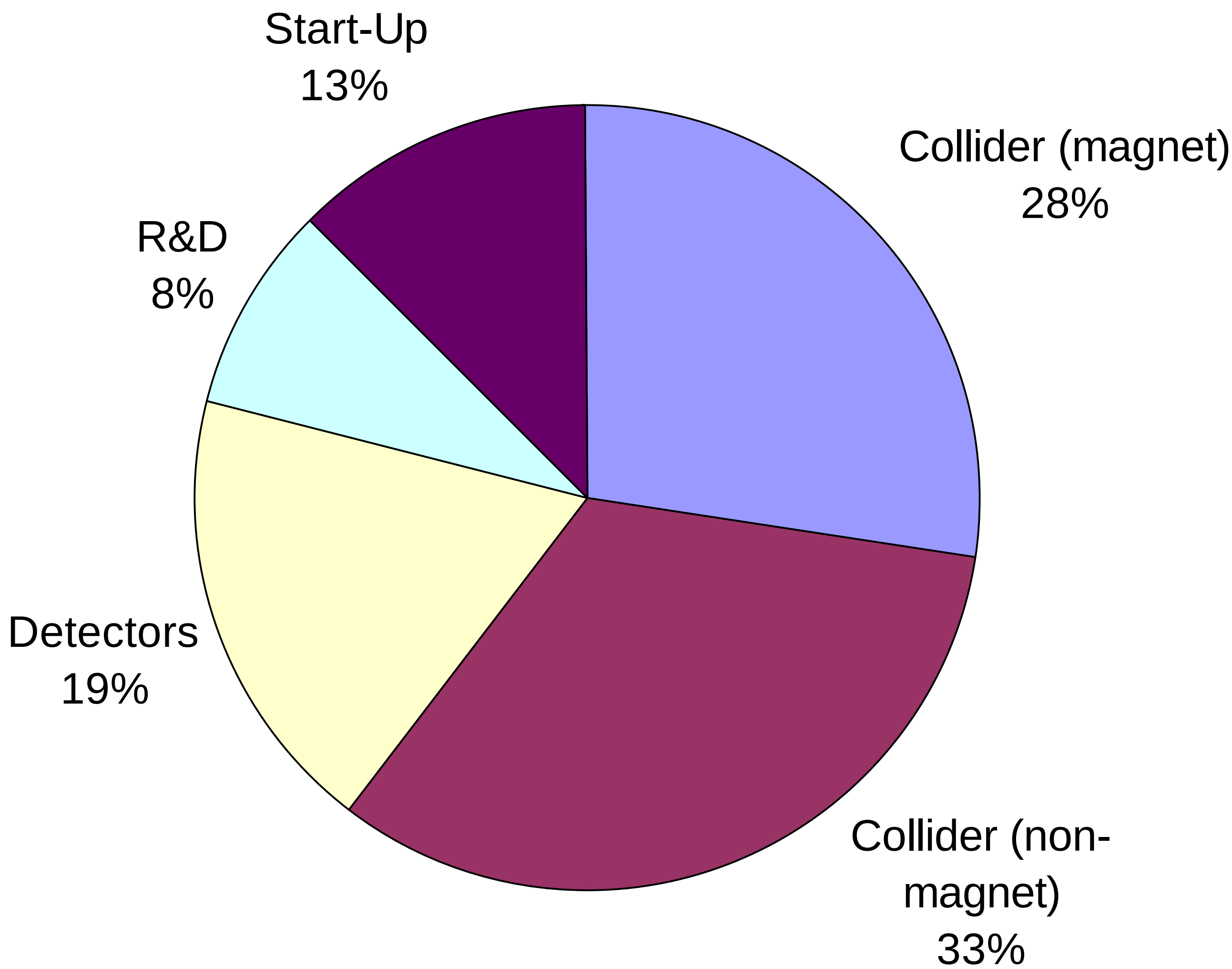
Cost Components of Production Dipole Magnets
Cost per magnet = $109,366

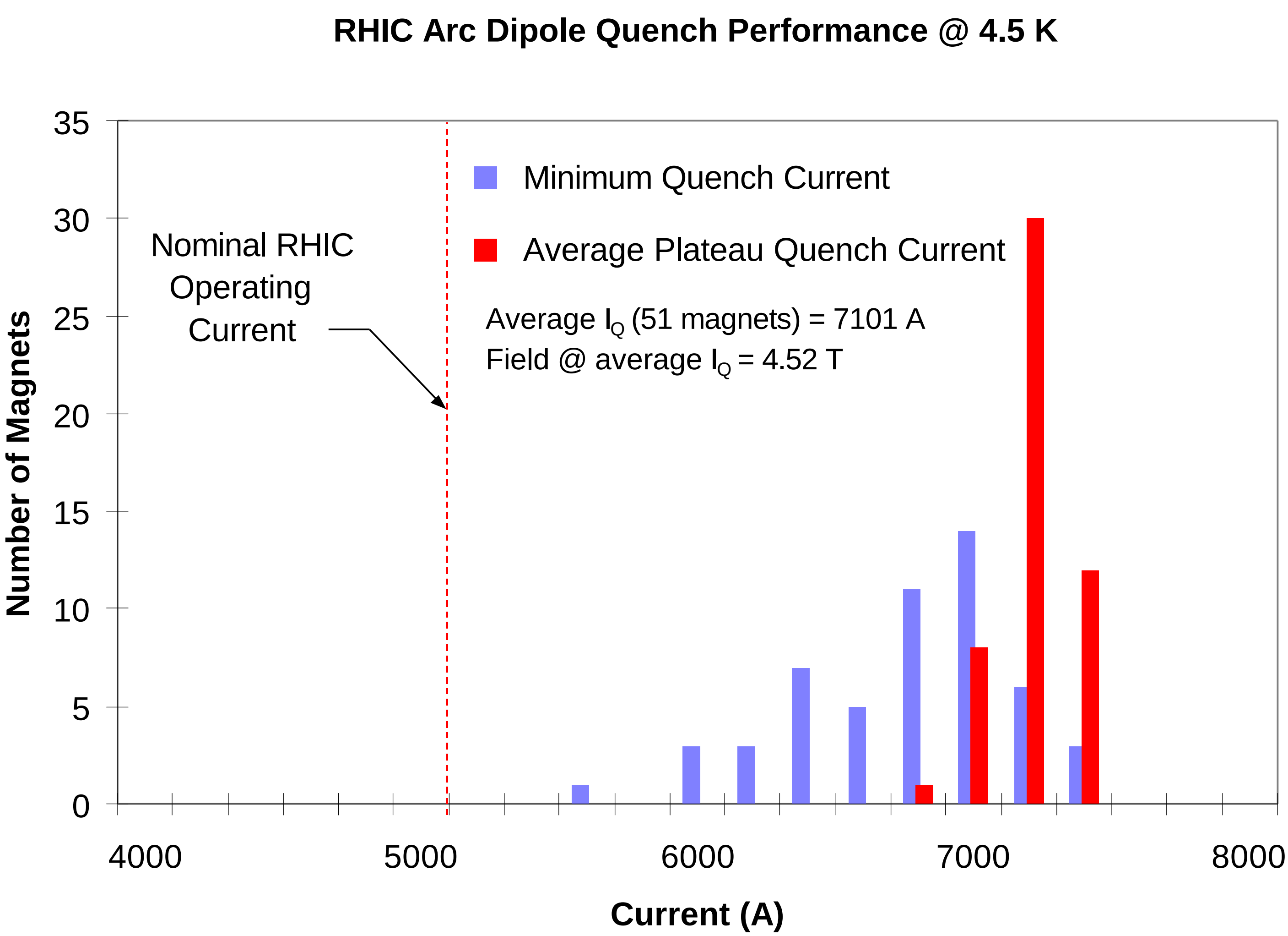


Labor and Material Costs of Production Dipole Magnets
Cost per magnet = $109,366



RHIC Project Cost Components




RHIC Arc Dipole Quench Performance @ 4.5 K
Minimum Quench Current
Average Plateau Quench Current
Nominal RHIC Operating Current
Average I_Q (51 magnets) = 7101 A
Field @ average I_Q = 4.52 T
Number of Magnets
Current (A)
0
5
10
15
20
25
30
35
4000
5000
6000
7000
8000

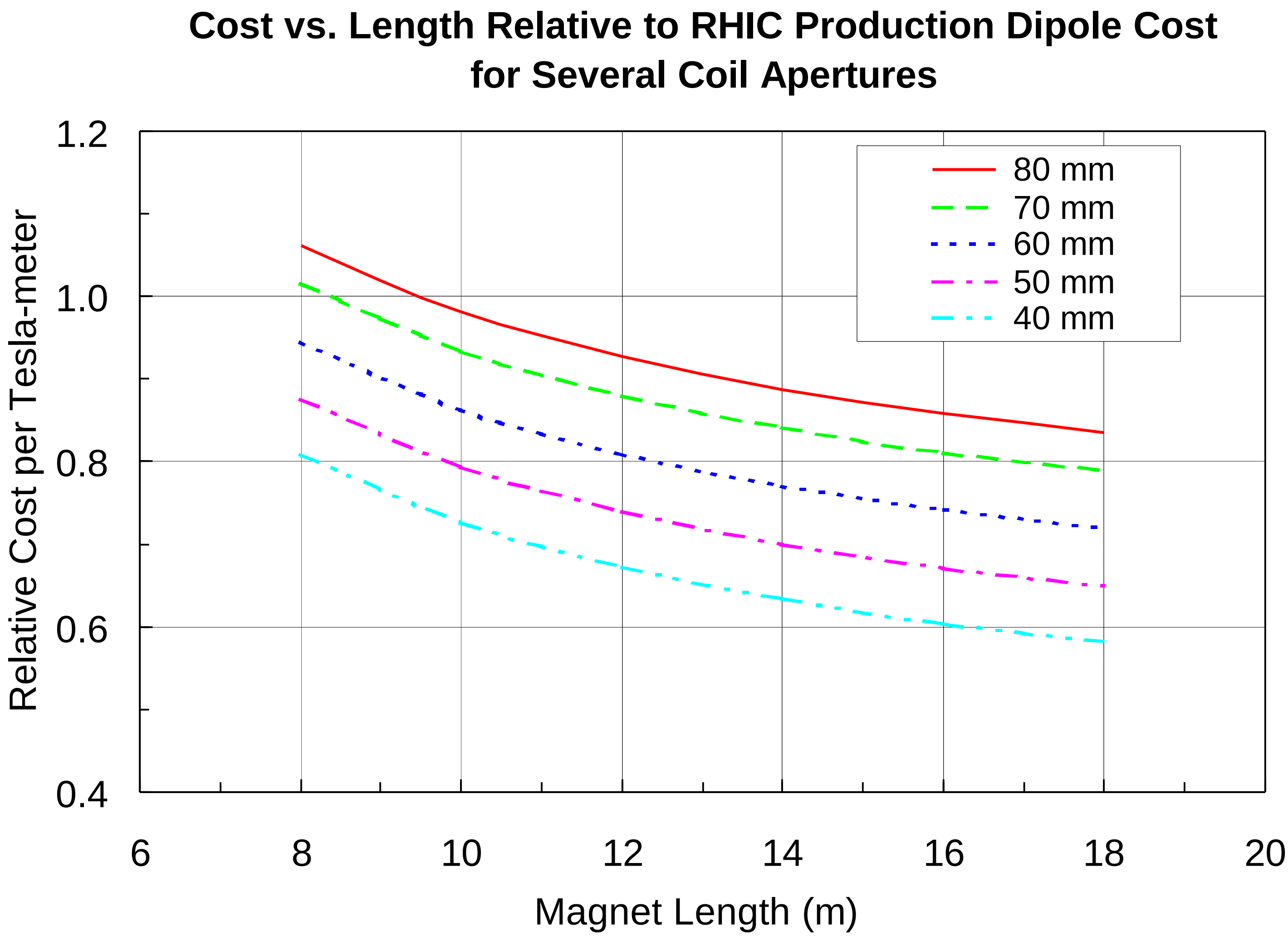
RHIC Production Dipole Magnets

Cost Summary

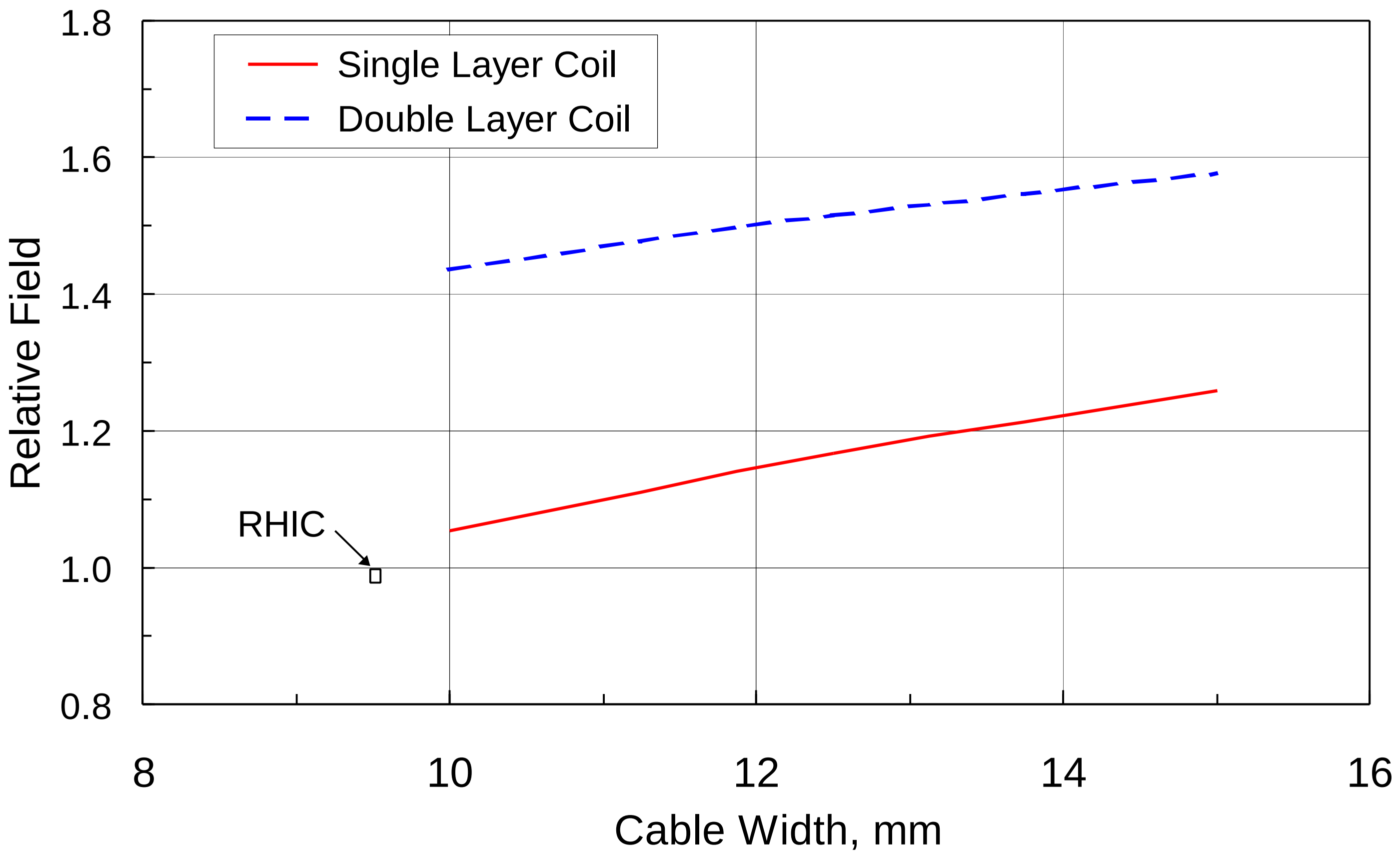
1993 Dollars

Item	Units	Value
Operating current @ 4.5 K	A	6175
(15 % below av. I_Q)		
Operating field @ 4.5 K	T	4.08
Operating field @ 4.2 K	T	4.30
Magnetic length	m	9.45
$\int$ Bdl	T-m	40.64
Cost per magnet	$	109,366
Cost per tesla-meter @ 4.2 K	$/T-m	2691

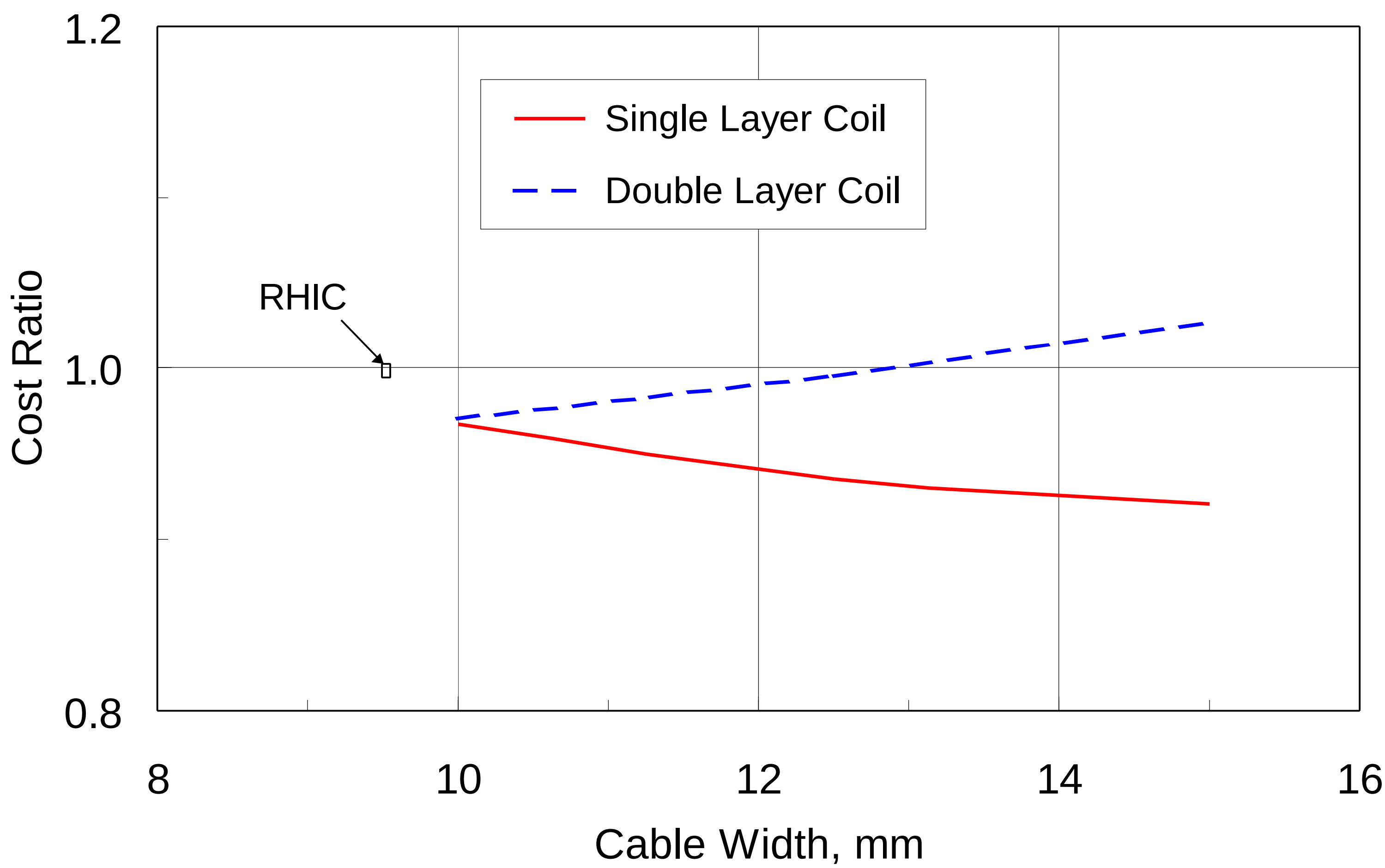
Included:	Cost of production, including delivery
	BNL-supplied materials
Excluded:	Cost of development at BNL
	BNL supervision and administration
	Testing at BNL


Cost vs. Length Relative to RHIC Production Dipole Cost
for Several Coil Apertures
80 mm
70 mm
60 mm
50 mm
40 mm
Relative Cost per Tesla-meter
1.2
1.0
0.8
0.6
0.4
6
8
10
12
14
16
18
20
Magnet Length (m)

Field Attainable, Relative to RHIC Dipoles, With Wider Cable and Second Coil



Ratio of Cost per Tesla-Meter for Dipoles with Wider Cable and Second Coil, Relative to RHIC Dipoles



Summary of Magnet Costs, Scaled

	$/T-m
RHIC production dipole cost	2691
Cost scaled for 18 m length, 40 mm aperture (58 %)	1561
Cost scaled for cable width of 15 mm (92 %)	1436

Tunnel Costs

The SSC tunnel is reported to have cost ~$3000/m

At Snowmass, the Colorado School of Mines indicated that $900/m might be possible for an 8' (2.44m) tunnel

- Minimum human access tunnel
- Impervious to water---lined and braced if necessary
- Reduced cost due to:
  - Automation and instrumentation improvements
  - More efficient muck removal methods

Cost of Arc Dipole Magnets and Tunnel for 100 TeV

Type	B_0 T	Cost \$/T-m	Dipole Cost Two Rings \$B	Tunnel (80% Fill) Length km	Tunnel (80% Fill) Cost @ \$900/m \$M
RHIC	4.30	2691	11.3	610	549
9.45 m length					
80 mm aperture					
Adjusted Size	4.30	1561	6.6	610	549
18 m length					
40 mm aperture					
Adjusted Field	5.70	1436	6.0	460	414
Single layer coil					
Cable 15 mm width					

Notes:

Field integral needed for 100 TeV is 2.1×10^6 tesla-meters

A 2-in-1 design could reduce dipole cost by 10-20 %

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SUPERCONDUCTING MAGNETS

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ABSTRACT

Superconducting dipole magnets for high energy colliders are discussed. As an example, the magnets recently built for the Relativistic Heavy Ion Collider at Brookhaven are reviewed. Their technical performance and the cost for the industry-built production dipoles are given. The cost data is generalized in order to extrapolate the cost of magnets for a new machine.

1. Introduction

1.1. Foreword

Superconducting dipole magnets for a machine as large as the Eloisatron have several important requirements: good performance, high reliability, low cost. To a large extent, these goals have been achieved in previous accelerator projects. Superconducting magnets built for existing colliders have proven reliable and provide very good field quality. Costs have been fairly well controlled (former SSC project excepted). These results, however, have not been achieved easily. The current cos θ magnet designs used in various accelerator projects, though they vary in detail, are the result of a very substantial development effort that has been carried out (in the US) primarily at three national laboratories over a period of many years.

It is unlikely that shortcuts will be found in the development of new types of superconducting magnets. The magnet system for the Eloisatron will have to be either an extension and evolution of existing magnet systems, or it will require a vigorous R&D program spread over many years. Time would be required to accomplish this work, not only the natural time that it takes to carry out such development work, but also the time required to overcome the prejudices that exist in the field because "it hasn't been done that way before". In addition, it will be a challenge to find the commitment and resources for such long term R&D work.

1.2. Design Options

The major technical choice to be made is the field level of the superconducting magnets. Intermediate field (3 - 10 T) cos θ magnets have been chosen for accelerator projects to date (Tevatron, CBA, HERA, UNK, SSC, RHIC and LHC). For future machines, both low field (<3 T) and high field (>10 T) magnet options have strong advocates, who argue that fresh approaches are needed if the next step in collider energy